DOCUMENT RESUME

ED 267 975 SE 046 497

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TITLE Elaboration of Cognitive Knowledge of Biology from Childhood to Adulthood.
PUB DATE [86]
NOTE 22p.
PUB TYPE Reports - Research/Technical (143)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS *Biology; Change; *Cognitive Development; *Developmental Stages; Higher Education; Intermediate Grades; *Knowledge Level; Piagetian Theory; *Science Education
IDENTIFIERS Science Education Research

ABSTRACT

Word association techniques were used to examine the growth of biological knowledge over a period of years, from fourth-grade to college students. Results were analyzed by classifying stimulus-response word pairs according to the nature of the relationship between the words in each pair. Three hypotheses were tested: (1) the proportion of enactive (verb) responses will be greatest among fourth-graders and will decrease with increasing knowledge of biology and with increasing maturity of subjects; (2) the pattern of word association responses in early adolescents (sixth-graders) will be different from that seen in younger and older groups, and will be consistent with concrete operational thought patterns as described by Piaget; and (3) as individuals learn more biology, the hierarchical organization of their knowledge will increase, as reflected by an increase of superordinate, subordinate, and definition responses. Results (based on response patterns) provide strong support for the Piagetian sensorimotor, concrete operational, and formal operational stages. They also reveal increasing hierarchical organization of knowledge with increased biology learning. A bibliography with 33 references concludes the report. (JN)

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ELABORATION OF COGNITIVE KNOWLEDGE OF BIOLOGY FROM CHILDHOOD TO ADULTHOOD

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"PERMISSION TO REPRODUCE THIS MATERIAL HAS BEEN GRANTED BY
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Fifty-seven stimulus words from general biology were presented to subjects ranging from fourth graders to college students. Their free word association responses were analyzed according to the relationships between stimulus and response words. Response patterns provide strong support for the Piagetian sensorimotor, concrete operational, and formal operational stages. They also reveal increasing hierarchical organization of knowledge with increased biology learning.

The acquisition of knowledge about a scientific domain is synonomous with building a mental representation of that domain. Knowledge is typically acquired over a long period of time and is drawn from both informal and formal learning experiences. At first one's knowledge is necessarily fragmented and piecemeal. With extended study and/or experience in a field, however, one gradually acquires the major concepts of the domain as well as a complex web of relational links between concepts.

Concepts are stored in what has come to be called semantic memory. One can think of the concepts as occupying nodes of the memory, and the nodes being linked together by relational pathways. Initially, many of the concepts have biographical information associated with them; the what, where, when, and how the concept was acquired may be as prominent as or more prominant than the features of the concept itself. This is what Tulving (33) described as episodic memory. Subsequently, through a process that is not well understood, many of the episodic referents associated with a concept are removed (or more likely, as features of the concept, reduced to minor importance, not usually activated or recalled) and the concept becomes part of the steadily increasing store of relatively objective, impersonal knowledge that a person possesses about the world and the language used to describe the world. A concept and its word labels are not synonymous. Word labels or signifiers and episodic referents are two among many types of features

of concepts held in memory storage.

Free word association represents one means of examining an individual's semantic network. A stimulus word is presented and an individual is asked to say what words come into his or her mind in response, without censorship, concentration, or other constraint. Those words which are elicited are presumed to occupy nodes closely linked to the stimulus word in the individual's semantic net, and those links which are used most often by the individual are presumed to be the ones that are accessed first. The specific nature of the links - that is, the perceived relationships between concepts - are not identified by the free word association task.

Word association studies were prominent in psychology during the first half of this century (e.g., 4, 5, 6, 7). and those studies contributed significantly to the development of current models of semantic memory (e.g., 1, 25). Most of the early studies involved common words. More recently, word association techniques have been used with technical vocabulary to study the acquisition of knowledge in scientific domains (e.g., 15, 16, 17, 18, 31, 32), typically over the duration of a single course.

In this study, word association techniques are used to examine the growth of biological knowledge over a period of years, from fourth grade to college students. Results were analyzed by classifying stimulus-response word pairs

according to the nature of the relationship between the words in each pair, using a method adapted from Moran and described in the Methods section. Three hypotheses were tested.

Hypothesis 1. The proportion of Enactive (verb) responses will be greatest among fourth graders and will decrease with (a) increasing knowledge of biology and (b) increasing maturity of subjects. There are at least two lines of evidence leading to this prediction. The first is a consequence of development, since children progress through a sensorimotor stage during which their thought patterns tend to be action-oriented (Piaget, 30). In this stage, children theoretically should use more action words than older individuals do. This prediction of Piagetian theory is supported empirically by Moran's (23) finding that Japanese, Chinese, and American children all evidence a primary response mode involving action words, while adults in all three cultures do not. The Enactive response mode, being a function of the developmental state of the individual rather than of the domain of the stimulus words, should occur with biological as well as common terms.

The second basis for this prediction is that the specialized jargon of biology consists almost entirely of nouns (11). As students becomes more knowledgeable about biology, they would be expected to more frequently utilize the noun-oriented jargon of the field.

Hypothesis 2. The pattern of word association responses in early adolescence (sixth-eighth graders) will be different from that seen in younger and older groups, and will be consistent with concrete operational thought patterns as described by Piaget.

According to Piaget (29, p.3):

> The third major period starts at around the age of seven or eight years and is characterized by the inception of operations. Initially these operations are concrete; that is, they are used directly on objects in order to manipulate these objects. For instance, the child can classify objects, or order them.....

The ability to classify objects implies knowledge of their distinguishing features. Thus, just as children in the sensorimotor stage of development are hypothesized to view biology from an Enactive or action-oriented perspective, so those in the concrete operational stage of development will be expected to view biology from an Iconic or descriptive perspective. The concrete operational period persists, according to Piaget, until 11-12 years of age, when the fourth stage begins (fourteen years may be a better approximation for American children).

Another reason for predicting that adolescent response patterns will differ from those of older and younger groups

is that adolescence is a time of change. It appears to be a period in which relatively little new learning takes place (8, 9, 3). It is also a time when differences in cognitive abilities between males and females first consistently appear (22), although this conclusion has been questioned (21). Further, it has been observed that the frequency of free word association responses drops by almost 50% from sixth grade to eighth grade (12). The literature is often confusing and contradictory with respect to details, but there is considerable evidence that adolescence is a time of cognitive (as well as other) change. The knowledge framework of adolescents appears to be undergoing reorganization and reorientation, shifting from the perspective of the child to the perspective of a young adult.

Hypothesis 3. As individuals learn more biology, the hierarchical organization of their knowledge will increase, as reflected by an increase of Superordinate, Subordinate, and Definition responses.

This hypothesis is predicted in part by Piagetian theory. As individuals move into the fourth stage of development, formal operational, they are able to manipulate abstract ideas as well as concrete objects, and so can recognize set-member, type-example, and other hierarchical relations. The hypothesis is also predicted by expert/novice studies that have shown that expert knowledge is more hierarchically organized than novice knowledge

(e.g., 19, 10). Thus, children should give relatively few responses reflecting a hierarchical organization of biological knowledge, while college students will more frequently give responses reflective of such a framework.

It should be noted that while this analysis is patterned after those of Moran (23,24), interpretation of the data reported here is somewhat more complex. Moran used stimulus words which were presumably familiar to all his subjects, and thus changes in the kinds of responses obtained could be attributed largely to development (maturation). This study uses technical vocabulary, at least some of which was unfamiliar to the younger subjects. Consequently, changes in response patterns are a function of both maturation and learning. Intelligence may represent a third variable influencing responses.

Methods

Subjects

Classes were selected for study from two predominantly white, upper middle class school districts in small university towns in two western states. This analysis involves, from community A, 20 fourth graders, 23 fifth graders, and 22 sixth graders; and from community B, 31 eighth graders, 27 eleventh graders, and 23 college undergraduates.

Task Administration

Fifty-seven stimulus words from a college biology syllabus (Appendix 1) were presented via synchronized slide-tape programs to students in regular class sessions. There were 55 nouns, one verb, and one adverb. Twenty seconds were allowed for responding to each term. Responses were written by each subject on standardized response sheets.

The presentation was continuous, with no break. All groups, including the youngest, remained largely on task to the end of the list. The task was presented to the younger students during science lessons and to older students during biology classes. The college group consists of students who had previously taken an introductory biology course and were now serving as tutors for that course; the task was presented to them during their weekly meeting.

Variables

Responses to each stimulus word were tallied by group. This provides a picture of the composite cognitive structures of the groups rather than of individual students. The analysis reported here is based upon the most frequent response given by each group to each stimulus word.

Three coders independently classified each stimulus-response word pair according to the criteria described below, adapted from but not identical to the categories used by Moran (23). Agreement between coders was high (85-90%),

and differences were resolved through discussion. Word pairs which could not be unambiguously classified were placed in an "Other" category. Specific scoring criteria were as follows:

ENACTIVE - the word pair is linked by action upon or in association with a referent (e.g., ANIMAL-run, OXYGEN-breathe). These are noun-verb or verb-noun pairs.

ICONIC - the word pair is linked by ascribing a quality to the referent (e.g., PLANT-green, SUGAR-sweet). These are noun-adjective and adjective-noun pairs.

FUNCTIONAL - this is a relatively large category that includes co-functional physical referents such as part-whole (CELL-nucleus) and adjacent (NUCLEUS-endoplasmic reticulum) relationships, cause-effect relationships (PIGMENTS-colors), and hierarchical relationships such as set-member (ANIMAL-dog) and member-member relationships (PLANT-animal). The reason these various categories are lumped together into one group is that many word pairs have multiple relationships and it is not possible to infer which interpretation may have prompted a subject's response (e.g., the nucleus is inside a cell, controls the cell, and is a defining feature of a eukaryotic cell). All FUNCTIONAL responses are noun-noun pairs.

SYNONYM/DEFINITION - the members of the word pair are essentially synonymous (e.g., ENVIRONMENT-surroundings,

EQUILIBRIUM-balance) or are related by definition (e.g., ORGANIC-carbon).

SUBORDINATE - the response word represents a subcategory or example of the stimulus word (e.g., SCIENCE-biology, RADIATION-X-ray).

SUPERORDINATE - the response word represents a set or class that includes the stimulus word (e.g., SPECIES-genus, FATS-lipids).

OTHER - this category includes all words that did not unambiguously fit into any of the above categories and words whose classification was not agreed upon by the three independent coders.

Moran (23) included a CONTRAST (opposites) category, but no such responses were obtained with biological stimulus words.

Results and Discussion

The mean frequency of each free word association variable in the performance of each group is summarized in Table 1. The data support Hypothesis 1 in that Enactive responses constitute a primary response mode among fourth graders and occur at relatively low levels thereafter. As Moran (23, p. 152) says:

> Such results are strongly supportive of a Piagetian design for a universal preoperational, representational child's cognitive dictionary.

> Just as "sensorimotor assimilation consists only of assimilating objects to schemes of (overt) action," representative assimilation seems empirically to emphasize assimilating signifiers of objects to (covert) representational schemes of action.

Using common words, Moran observed that the decrease in Enactive responses as children matured was accompanied by a concomitant increase in logical responses, including both Definition and Contrast (black-white, hot-cold) word pairs. With biological terms, we find a quantitatively similar increase of Definition word pairs, but no Contrast responses were obtained with any biology stimulus words.

The pattern of word associations in early adolescence is different from that seen in younger and older groups, supporting Hypothesis 2. The salient feature is the high proportion of Iconic responses given by younger students and peaking at about 14 years of age (eighth grade). The relatively high frequency of Iconic responses may be taken as an indication of concern with the features of concrete things, reflective of a concrete operational stage of development as described by Piaget. This stage spans a number of years and is followed by formal operational thought beginning at about age 12 or 14. Eighth graders also exhibit a marked increase in definition responses (in comparison to younger groups).

The data also support Hypothesis 3. As individuals learn more biology, there is a steady increase in the

proportion of Definition, Subordinate, and Superordinate responses, up to the level of college undergraduate biology tutors. The increase in frequency of these response modes provide strong evidence for the increasing hierarchical organization of the subjects' knowledge about the biological domain. They also reflect the increasing ability of subjects to manipulate abstract ideas, as expected in the formal operational stage of development.

The Other category is very large (nearly 50%) among fourth graders. This can be attributed in part to the lack of subject knowledge about some of the stimulus words and in part to lack of coder knowledge about the worldviews of fourth graders. The Other category drops to about 15% among college students.

The percentages of responses in each category, summarized in Table 1, are calculated on the basis of the total response set. One can ask whether these patterns change if the Other responses are first subtracted and percentages calculated using remaining responses. These calculations were performed; the patterns remained similar.

Conclusion

Free word association provides an interesting means for assessing the growth of biological knowledge over time. Analysis of response type, as reported here, reveals the interaction between maturation and learning. The results are consistent (a) with Piagetian stages of development and (b) with the notion that education leads to shared knowledge

as the students' cognitive structures gradually become more and more similar to those of the teachers.

Conceptual change evolves from a variety of conditions, including such things as learning, maturation of the nervous system, changes in the "mattering map", and changes in physiological states of individuals (as with hormone levels). Some researchers argue that there is a change in the way information is represented in memory at various stages of development (30, 33). Others suggest that the principle changes are those occurring in the processing capacity of the conceptual system (2, 27), in the elaboration of superordinate concepts with which to organize subordinate concepts (e.g., 14),and in the acquisition of metaconceptual knowledge (e.g., 13, 26, 20).

This study is consistent with the latter viewpoints. The way in which knowledge is represented in memory does not necessarily change with maturation and learning, but one's perspective about which features of concepts are salient and important does change. The assumption is that, under ordinary conditions, only the most prominent features of a concept are invoked by memory. This shifting perspective is what is meant (in part) by one's worldview. Further, while cognitive change is a continuous, ongoing process, there are certain periods in development and learning where change occurs at relatively rapid rates and in predictable directions, as observed by Piaget.

Acknowledgements. Deep appreciation is expressed to N. Schoenberg and N. Porter, undergraduate biology students who contributed in many ways to the design of the study and to collection and analysis of the data. Many thanks also to J. I. Lipson for suggesting the word association technique and for many hours of discussion concerning experimental design, theory, and interpretation. Finally, thanks to C. Spring for his many thoughtful insights regarding interpretation of the data.

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Appendix 1. Stimulus Word List

ANIMAL	ATOM	BACTERIA
BIOLOGY	BONDING	CARBOHYDRATE
CARBON	CATALYST	CELL
CELLULOSE	CHROMOSOME	EGGS
ELEMENT	ENERGY	ENVIRONMENT
EQUILIBRIUM	EVOLUTION	FATS
FITNESS	FUNGI	GENERATION
GENES	HEREDITY	HORMONES
HYPOTHESIS	MEMBRANE	MOLECULE
NUCLEUS	OILS	ORGANIC
ORGANISMS	ORGANS	OSMOSIS
OXYGEN	DNA	PHOTSYNTHESIS
PIGMENTS	PLANT	PROTEIN
RADIATION	REACTION	REPRODUCTION
RESPIRATION	SCIENCE	SOLUTION
SPECIES	SPONTANEOUS	STARCH
STEROIDS	SUGAR	SUNLIGHT
SYNTHESIS	TISSUE	TRAIT
VIRUS	VITAMINS	WATER